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Persistent photoconductivity in p-type $Al_{0.5}Ga_{0.5}As/GaAs/Al_{0.5}Ga_{0.5}As$ heterostructures

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Abstract. Illumination of a double $p - Al_{0.5}Ga_{0.5}As/GaAs/Al_{0.5}Ga_{0.5}As$ heterostructure by a red light emitting diode results in a negative photoconductivity that, after the diode is switched off, slowly relaxes to a positive persistent photoconductivity, characterised by about 1.5 increase of a two-dimensional hole concentration. This metastable state may be explained in a framework of the model in which deep electron traps are supposed to be located above the Fermi level on the inverted heterointerface.

Introduction

In recent years a great interest in the study of GaAs/AlAs (GaAs/AlGaAs) superlattices has been connected with a striking difference in the electronic properties of normal "AlAs on GaAs" and inverted "GaAs on AlAs" interfaces. We study how the presence of an inverted heterointerface influences photoconductivity in these structures. Previously it was observed that the illumination of a single p-type $GaAs/Al_{0.5}Ga_{0.5}As$ heterostructure doped with Be by a red light emitting diode (LED) at liquid helium temperature results in a negative photoconductivity (NPC) that, after the light is switched off, slowly relaxes to the initial resistivity in dark [1]. In the present work we report on the effect of a red LED illumination on a conductivity of uniaxially compressed p-type double heterostructure $Al_{0.5}Ga_{0.5}As/GaAs/Al_{0.5}Ga_{0.5}As$, that differs from the structure in Reference 1 by the presence of the inverted heterointerface.

1. Experiment

At the beginning we repeated the results of Ref. [1] on the similar single $GaAs/Al_{0.5}Ga_{0.5}As$ heterojunction, that was grown by molecular beam epitaxy (MBE) in [001] direction with the normal sequence of AlGaAs on GaAs and modulation doped with Be (Fig. 1). The samples were prepared by photolithography in a Hall bar configuration with current being along [110] direction. At the temperature of experiment $T = 1.5$ K the hole density is $N = 2.8 * 10^{15}\ \mathrm{m}^{-2}$. The characteristic LED photon energy is 1.9 eV. Our results are in a good agreement with ones from Ref. [1].

The double p-type $Al_{0.5}Ga_{0.5}As/GaAs/Al_{0.5}Ga_{0.5}As$ heterostructure was grown under the similar conditions as the single one and modulation doped with Be in $Al_{0.5}Ga_{0.5}As$. The process of the sample preparation and experimental details were not changed. Illumination of the samples with the red LED also caused the NPC effect. However in this case, when the LED was switched off, the non-exponential transient process led to the positive persistent photoconductivity (PPC) characterised by higher values of carrier density and mobility in

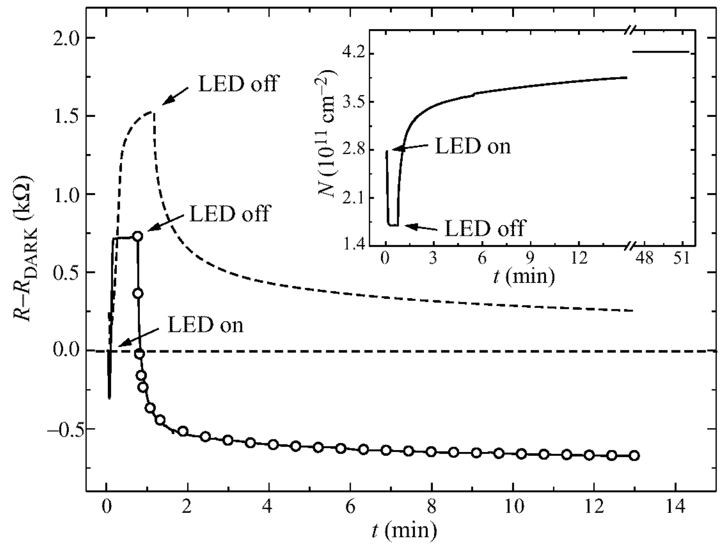

Fig. 1. NPC and PPC effects in single p − GaAs/$Al_{0.5}Ga_{0.5}As$ (dashed line) and double p − $Al_{0.5}Ga_{0.5}As$/GaAs/$Al_{0.5}Ga_{0.5}As$ (solid line) heterostructures. Open circles are the result of fitting according to Ref. [1]. The $N(t)$ dependence in p−$Al_{0.5}Ga_{0.5}As$/GaAs/$Al_{0.5}Ga_{0.5}As$ is represented in the insert.

comparison with the initial state in dark (Fig. 1). The initial state in dark could be restored by warming the sample up to room temperature and slow cooling it to 1.5 K.

The carrier concentration was controlled by the Hall effect and quantum transport measurements: Shubnikov–de Haas (SdH) oscillations and quantum Hall (QH) effect. The numerical values of carrier concentration in dark and in PPC state, calculated from the Hall effect and the frequency of SdH oscillations, are the same within the experimental error about 2%. These data in connection with the fact, that SdH oscillations and QH plateaus in Fig. 2 are not distorted after illumination, ensure that the observed PPC is not connected with the parallel conductivity described in Ref. [2]. In the PPC state we consider the value after 1 hour after the LED was switched off.

The transient process between NPC and PPC states is not exponential and may be well fitted by the logarithmic law like it was done in Ref. [1].

2. Discussion

The direct energy gap E_g in $Al_{0.5}Ga_{0.5}As$ is 2.14 eV at $T = 4.2$ K and it is larger than the red LED photon energy 1.9 eV. Therefore the direct band to band transitions under illumination are not possible. Following the conception of the NPC effect developed in Ref. [1], we have to suppose the presence of deep donor-like states located a bit below the Fermi level (FL) in the spacer just near the heterointerface. Being below the FL these states are neutral. Under illumination electrons photogenerated from these states to the conduction band are swept by the junction electric field into the quantum well (QW) and recombine with 2D holes, causing the reduction of their density. In the single heterojunction investigated in Ref. [1], as well as in the present work, the decay process to the initial state in dark is connected with a tunneling of holes from the positively charged exited donor like states back to the QW.

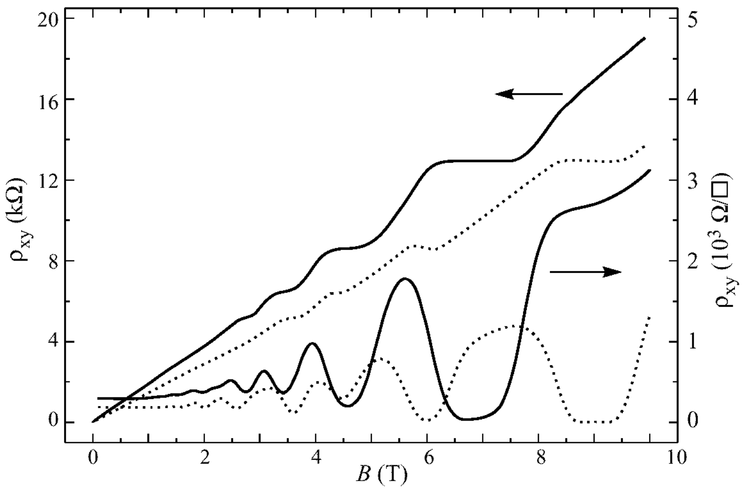

Fig. 2. SdH oscillation and QH efect in p − $Al_{0.5}Ga_{0.5}As/GaAs/Al_{0.5}Ga_{0.5}As$ dark (solid lines) and PPC (dashed lines) states.

The PPC effect in the double heterostructure is characterised by a considerable increase of the 2D hole concentration compared with one in dark. Since the p − $Al_{0.5}Ga_{0.5}As/GaAs/Al_{0.5}Ga_{0.5}As$ structure differs from p − $GaAs/Al_{0.5}Ga_{0.5}As$ by the presence of the second inverted heterointererface, the excess of 2D holes may be explained if we assume that during the transient process some amount of electrons is captured by deep electron traps located on this interface above the FL. It was recently established by deep-level transient spectroscopy that a series of four well defined deep levels is characteristic of inverted $GaAs/Al_xGa_{1-x}As$ interface grown by conventional MBE technique. These levels originate from intrinsic defects which are associated with arsenic vacancies and antisites acting like electron traps [3]. So the observed PPC effect is most probably associated with them.

The results are especially important for laser diodes because the observed PPC effect in AlGaAs/GaAs/AlGaAs let us suppose that electron traps at inverted heterointerfaces of quantum wells may be a source of nonradiative recombination processes.

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